# Surgical repair of ruptured abdominal aortic aneurysms in the state of Maryland: Factors influencing outcome among 527 recent cases

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*Purpose:* Abdominal aortic aneurysm (AAA) rupture has been historically associated with high operative mortality rates. In this community-based, cross-sectional study, we examined factors influencing outcome after operations performed for ruptured AAA (rAAA).
*Methods:* An analysis of a state database identified 3820 patients who underwent AAA repair between 1990 and 1995, including 527 (13.8%) who had an operation for an rAAA. Demographic variables examined included patient age, gender, race, associated comorbidity rates, operative surgeon experience with rAAA, and annual hospital rAAA and total AAA operative volumes. Outcomes measured included operative mortality rates, hospital length of stay, and charges.
*Results:* Operative mortality rates increased significantly with advancing age ($P < 0.0001$) but were not related to gender ($P = 0.474$) or race ($p = 0.598$) and were significantly lower among patients with hypertension ($P = 0.006$) or pulmonary disease ($P = 0.045$). There was no relationship between hospital rAAA or total AAA volume and rAAA repair mortality rate, although high-volume surgeons (i.e., performing more than 10 rAAA repairs) had decreased mortality rates and hospital charges compared with other surgeons. Hospital lengths of stay and charges increased with age among survivors, but not nonsurvivors, of rAAA repair. Despite a stable incidence of rAAA repairs during the study interval and no significant change in the mean age of patients undergoing operation or the percentage of operations performed by high-volume surgeons, the statewide mortality rate declined from 59.3% to 43.2% ($P = 0.039$).
*Conclusion:* The incidence of rAAA does not appear to be declining. Although operative rAAA repair continues to be associated with substantial risk and remains an especially lethal condition among the elderly, the operative mortality rate has declined in recent years in Maryland. Lower operative mortality rates and hospital charges are associated with operations performed by high-volume surgeons. (J Vasc Surg 1998;28:413-21.)

Abdominal aortic aneurysm (AAA) rupture has been historically associated with high operative mortality rates, with numerous reports documenting overall mortality rates of approximately 50%.[1-5] Several factors have been found to influence mortality rate after the repair of a ruptured AAA (rAAA), including clinical (patient age, platelet count, and level of consciousness),[2,6-9] aneurysm-specific (suprarenal extension),[2] and intraoperative (blood loss) variables.[6,10] Two potentially modifiable risk factors include the experience of the operating surgeon and annual hospital volume of AAA operation.[11-14] Although elective AAA repair has become progressively safer in recent years, most studies have indicated that the mortality rate after rAAA repair has not substantially diminished.[13-15] Studies of outcome after rAAA repair based on single-institution series can reflect selection or referral bias, and there have been few population-based cohort studies in which the

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**Table I.** Demographics and outcomes of 527 patients undergoing repair for rAAA

| *Factor* | *Entire group* | *Survivors* | *Nonsurvivors* |
|---|---|---|---|
| n | 527 | 277 | 250 |
| Age (yr, mean) | 71.9 ± 8.5 | 69.7 ± 8.2 | 74.4 ± 8.2 |
| Age (yr, range) | 39 - 94 | 39 - 91 | 44 - 94 |
| Medical complexity score | 3.18 ± 0.04 | 3.10 ± 0.06 | 3.26 ± 0.06 |
| Admitted from ED (%) | 89.4 | 84.5 | 94.8 |
| Mortality rate (%) | 47.4 ± 2.2 | 0 | 100 |
| LOS (days) | 11.8 ±0.6 | 17.1 ± 0.9 | 6.0 ± 0.7 |
| ICU LOS (days) | 5.4 ± 0.3 | 6.5 ± 0.4 | 4.0 ± 0.5 |
| Charge ($) | 27,015 ± 957 | 30,640 ± 1378 | 22,999 ± 1273 |
| Total charge ($ million) | 14.2 | 8.49 | 5.75 |

*ED*, emergency department; *ICU*, intensive care unit.
All values are listed as mean ± SEM, except for age, where the mean ± SD is given. The difference in all variables between survivor and nonsurvivor subgroups was statistically significant.

outcome after rAAA repair was assessed.[13-15] The current study was undertaken to provide a contemporary assessment of the outcome of rAAA surgery across a broad spectrum of clinical practice and to identify factors influencing operative mortality and costs.

## PATIENTS AND METHODS

We identified all patients undergoing operative repair of an rAAA in all nonfederal acute care hospitals in the state of Maryland between 1990 and 1995 by using the Maryland Health Services Cost Review Commission (HSCRC) database. A combination of search terms based on the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9) codes was used to restrict the records to patients with an rAAA who received an operative repair of the aneurysm as the primary therapy: (1) presence of a diagnostic code for rAAA (441.02 or 441.3) in the primary diagnostic code position, (2) presence of a procedural code for AAA repair (38.34, 38.44, 38.64, 38.84, or 39.54) in the primary procedural code position, and (3) presence of one of the 10 vascular diagnosis-related group (DRG) codes (5, 110-114, 119, 120, 478, or 479). Only records satisfying all three criteria were selected for examination. This combination of search codes was used to eliminate thoracoabdominal aortic aneurysms, nonruptured AAA repairs, and aneurysm repair performed secondary to another operation and to minimize coding errors. The algorithm was verified by examining records at The Johns Hopkins Hospital and Sinai Hospital of Baltimore; all records retrieved by the algorithms were verified as appropriate, and no known cases were excluded. Nonruptured AAA repairs were identified by substituting the diagnostic code for nonruptured AAA (441.4) for the codes for rAAA in the first portion of the search criteria listed above.

Patient variables that were analyzed included race, gender, age, hypertension (diagnostic codes 401 to 405), smoking (diagnostic codes 305.1, 491.0, 472.1, or 528.6), diabetes (diagnostic code 250), heart disease (diagnostic codes 391, 394 to 398, 402, 404, 411 to 414, 416, or 425), chronic obstructive pulmonary disease ([COPD] diagnostic codes 415.0, 416.8 to 416.9, 491 to 494, or 496), renal disease (diagnostic codes 585 to 586, V42.0, V45.1, or V56),[16,17] and medical complexity score. The medical complexity score is determined with the use of a proprietary software package at the HSCRC that applies a stepwise quantitative and qualitative algorithm that considers patient primary and secondary diagnoses to assess overall patient comorbidity; it is graded in increasing severity from 1 through 4. However, because the algorithm is derived from underlying risk factors otherwise included in the logistic regression analysis (see below), the complexity score was omitted from that analysis.

Outcomes that were studied included in-hospital death, hospital length of stay (LOS), and total hospital charges; in Maryland, hospital charges are established by the HSCRC to reflect cost. Hospitals were stratified as low- (n = 26), medium- (n = 13), or high- (n = 6) volume institutions regarding rAAA repair operations, defined as performing fewer than 10, 10 to 19, or 20 or more rAAA repairs throughout the study period, respectively. Hospitals were stratified as low- (n = 23), medium- (n = 12), or high- (n = 12) volume institutions regarding AAA operations, defined as performing fewer than 50, 50 to 99, or 100 or more nonruptured AAA repairs, respectively. Surgeons were stratified as low- (n = 199), medium- (n = 20), or high- (n = 7) volume surgeons if they performed 1 to 4, 5 to 9, or 10 or more rAAA repairs, respectively. Maryland state

Table II. Effect of age on rAAA outcome

| *Age group (yr)* | *n* | *Medical complexity score* | *LOS (days)* | *Charge ($)* | *Mortality rate (%)* |
|---|---|---|---|---|---|
| All patients | | | | | |
| <65 | 99 | 3.02 ± 0.1 | 11.1 ± 1.9 | 25,066 ± 2017 | 28.3 ± 4.5 |
| 65 to 69 | 92 | 3.09 ± 0.1 | 12.6 ± 1.5 | 26,960 ± 2401 | 37.0 ± 5.1 |
| 70 to 79 | 240 | 3.23 ± 0.1 | 12.4 ± 1.0 | 28,248 ± 1498 | 51.7 ± 3.2 |
| ≥80 | 96 | 3.30 ± 0.1 | 10.4 ± 1.2 | 25,996 ± 1999 | 66.7 ± 4.8 |
| *P* | | 0.163* | 0.36* | 0.51* | <0.0001† |
| Survivors | | | | | |
| <65 | 71 | 2.87 ± 0.1 | 14.4 ± 1.4 | 27,280 ± 2573 | |
| 65 to 69 | 58 | 2.93 ± 0.1 | 16.4 ± 1.7 | 29,340 ± 2893 | |
| 70 to 79 | 116 | 3.22 ± 0.1 | 19.0 ± 1.6 | 33,433 ± 2290 | |
| ≥80 | 32 | 3.47 ± 0.1 | 17.6 ± 2.0 | 30,324 ± 3603 | |
| *P* | | 0.015* | 0.007* | 0.014* | |
| Nonsurvivors | | | | | |
| <65 | 28 | 3.39 ± 0.2 | 2.9 ± 1.0 | 19,454 ± 2655 | |
| 65 to 69 | 34 | 3.35 ± 0.2 | 6.1 ± 2.3 | 22,899 ± 4192 | |
| 70 to 79 | 124 | 3.23 ± 0.1 | 6.2 ± 1.0 | 23,397 ± 1861 | |
| ≥80 | 64 | 3.27 ± 0.1 | 6.8 ± 1.3 | 23,831 ± 2371 | |
| *P* | | 0.74* | 0.53* | 0.95* | |

*Kruskal-Wallis test.
†$\chi^2$ test.

population data between 1990 and 1995 were provided by the Maryland Office on Aging. The incidence of AAA and rAAA repair in the population was calculated by comparing the number of AAA or rAAA repairs throughout the state per year with the state population in that year.

Categorical variables were analyzed by Pearson's $\chi^2$ test or Fisher's Exact Test. Continuous variables were analyzed by analysis of variance for parametric variables and the Mann-Whitney *U* test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis.

## RESULTS

**Effects on rAAA mortality rate.** Between 1990 and 1995, 3820 patients underwent AAA repair, including 527 (13.8%) who presented with an rAAA. The demographic characteristics of patients undergoing rAAA repair are presented in Table I. The operative mortality rate increased significantly with advancing age (Table II). Although medical complexity increased with advancing age, this trend was not statistically significant among the entire patient population (Table II). There was, however, a significant correlation between medical complexity score and age among survivors of operative repair but not among nonsurvivors, who had uniformly high complexity scores (Table II).

Female patients were significantly older (75.0 ± 0.7 vs 71.2 ± 0.4 years; $P < 0.0001$, Mann-Whitney *U* test) than male patients, but there was no difference in mean complexity score (3.2 ± 0.1 vs 3.2 ± 0.1 days, $P = 0.87$) between female and male patients. Female patients experienced increased mortality rates compared with male patients, although this difference was not statistically significant (Table III). Operative mortality rates also were higher in white patients compared with black patients, but this difference was not significant (Table III). The mean age of white patients (72.0 ± 0.4 years) was not different from that of black patients (71.5 ± 2.0 years; $P = 0.946$, Mann-Whitney *U* test), and there was no difference in mean medical complexity score (3.2 ± 0.1 vs 3.2 ± 0.1, $P = 0.54$) between black and white patients.

Operative mortality rate was unrelated to hospital rAAA and total AAA volume (Table IV). There was no difference in mean patient age or medical complexity scores among the low-, medium-, and high-volume rAAA centers (Table IV). Although there were no differences in mean age or medical complexity scores among patients operated on by high-, medium-, and low-volume rAAA surgeons, patients undergoing operation by high-volume rAAA surgeons had significantly lower postoperative mortality rates (Table V).

By univariate analysis, the presence of hypertension, diabetes, and COPD was correlated with a statistically significant lower mortality rate, whereas the presence of smoking, heart disease, and renal disease was correlated with statistically insignificant decreases (Table III). Multivariate analysis identified increased mortality rate with increasing age and decreased mortality rate with high surgeon volume, hypertension,

**Table III.** Effect of patient demographic and comorbid variables on rAAA mortality rate

| | *Factor* | *n* | *Mortality rate (%)* | *P** |
|---|---|---|---|---|
| Gender | Female | 108 | 51.9 ± 4.8 | 0.33 |
| | Male | 419 | 46.3 ± 2.4 | |
| Race† | White | 494 | 48.2 ± 2.3 | 0.24 |
| | Black | 28 | 35.7 ± 9.2 | |
| Hypertension | Yes | 135 | 33.3 ± 4.1 | <0.0001 |
| | No | 392 | 52.3 ± 2.5 | |
| Diabetes | Yes | 30 | 26.7 ± 8.2 | 0.023 |
| | No | 497 | 48.7 ± 2.2 | |
| COPD | Yes | 115 | 36.5 ± 4.5 | 0.008 |
| | No | 412 | 50.5 ± 2.5 | |
| Smoker | Yes | 10 | 30.0 ± 15.3 | 0.35 |
| | No | 517 | 47.8 ± 2.2 | |
| Cardiac disease | Yes | 80 | 37.5 ± 5.4 | 0.07 |
| | No | 447 | 49.2 ± 2.4 | |
| Renal disease | Yes | 9 | 44.4 ± 17.6 | 0.99 |
| | No | 518 | 47.5 ± 2.2 | |

*Fisher's Exact Test.
†Five patients were listed as "other" and were omitted from the analysis.

**Table IV.** Effect of hospital volume on rAAA mortality rate

| | *rAAA class* | | *AAA class* | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Class* | *n** | *Mortality (%)* | *n†* | *Mortality(%)* | *Age (yr)‡* | *Medical complexity score‡* | *LOS (days)‡* | *Charge ($)‡* |
| Low | 147 | 45.6 ± 4.1 | 63 | 54.0 ± 6.3 | 71.4 ± 0.7 | 3.22 ± 0.08 | 14.0 ± 1.3 | 31,105 ± 2154 |
| Medium | 191 | 49.2 ± 3.6 | 189 | 46.0 ± 3.6 | 72.7 ± 0.6 | 3.24 ± 0.07 | 10.4 ± 1.0 | 25,243 ± 1471 |
| High | 189 | 47.1 ± 3.6 | 275 | 46.9 ± 3.0 | 71.6 ± 0.6 | 3.10 ± 0.07 | 11.6 ± 0.9 | 25,624 ± 1427 |
| *P* | | 0.80§ | | 0.53§ | 0.27‖ | 0.36‖ | 0.15‖ | 0.10‖ |

*n is the total number of rAAA repairs per hospital rAAA class. rAAA class is based on fewer than 10 (n = 26 hospitals), 10 to 19 (n = 13), or 20 or more (n = 6) rAAA repairs per hospital.
†n is the number of rAAA repairs per hospital AAA class. AAA class is based on fewer than 50 (n = 23 hospitals), 50 to 99 (n = 12) or 100 or more (n = 12) total AAA operations.
‡Based on rAAA class.
§$\chi^2$ test.
‖Kruskal-Wallis test.

and pulmonary disease; there was no significant correlation with gender, race, diabetes, smoking history, cardiac disease, or renal disease (Table VI).

**Effects on rAAA hospital LOS and charge.** Hospital LOS and mean charges were unrelated to age among all patients but increased with age among survivors of rAAA repair (Table II). There was no difference in LOS (12.1 ± 1.7 vs 11.8 ± 0.6 days, *P* = 0.65), intensive care unit (ICU) LOS (5.1 ± 0.8 vs 5.4 ± 0.4 days, *P* = 0.28), or hospital charge ($26,716 ± $2333 vs $27,092 ± $1044, *P* = 0.63) between female and male patients. Similarly, there was no difference in LOS (12.3 ± 2.1 vs 11.8 ± 0.6 days, *P* = 0.26), ICU LOS (4.4 ± 1.0 vs 5.4 ± 0.4 days, *P* = 0.70), or hospital charge ($29,485 ± $3977 vs $26,866 ± $993, *P* = 0.21) between black and white patients.

Although the mean LOS was longer and hospital charges were higher at low-volume hospitals than at medium- and high-volume hospitals, these differences were not significant (Table IV). However, patients undergoing operation by high-volume rAAA surgeons experienced a comparable LOS but significantly lower hospital charges compared with patients undergoing operation by low- and medium-volume surgeons (Table V).

**Trends over time.** The incidence of AAA repair varied insignificantly between 1.17 and 1.39 per 10,000 population during the course of the study, and the incidence of rAAA repair remained stable during the study interval, varying between 0.15 and 0.20 per 10,000 population, or 11% to 15% of all AAA repairs (Table VII). However, despite a constant number of rAAA repairs, operative mortality

**Table V.** Effect of surgeon volume on rAAA mortality rate

| *Class* | *n** | *Mortality rate (%)* | *LOS (days)* | *Charge ($)* | *Age (yr)* | *Medical complexity score* |
|---|---|---|---|---|---|---|
| Low | 315 | 50.8 ± 2.8 | 11.7 ± 0.8 | 27,362 ± 1283 | 72.1 ± 0.5 | 3.19 ± 0.06 |
| Medium | 121 | 47.1 ± 4.6 | 11.6 ± 1.0 | 28,575 ± 1748 | 72.1 ± 0.8 | 3.22 ± 0.09 |
| High | 91 | 36.3 ± 5.1 | 12.4 ± 1.8 | 23,740 ± 2356 | 71.3 ± 0.9 | 3.08 ± 0.10 |
| *P* | | 0.05† | 0.46‡ | 0.018‡ | 0.49‡ | 0.39‡ |

*Surgeon class is based on 1 to 4 (n = 199 surgeons), 5 to 9 (n = 20), or 10 or more (n = 7) rAAA repairs per surgeon. n represents the number of patients per surgeon class.
†$\chi^2$ test.
‡Kruskal-Wallis test.

**Table VI.** Multivariate analysis of factors affecting rAAA mortality rate

| *Variable** | *Regression coefficient* | *Odds ratio* | *95% Confidence interval* | *P†* |
|---|---|---|---|---|
| Age | 0.959 | 2.61 | 1.77 - 3.84 | <0.0001 |
| High-volume surgeon | –0.616 | 0.54 | 0.33 - 0.88 | 0.014 |
| Gender | 0.167 | 1.18 | 0.75 - 1.87 | 0.474 |
| Race | –0.234 | 0.79 | 0.33 - 1.89 | 0.598 |
| Hypertension | –0.633 | 0.53 | 0.34 - 0.83 | 0.006 |
| Diabetes | –0.692 | 0.50 | 0.21 - 1.21 | 0.124 |
| COPD | –0.467 | 0.63 | 0.40 - 0.99 | 0.045 |
| Smoking | –0.449 | 0.64 | 0.15 - 2.68 | 0.540 |
| Cardiac disease | –0.248 | 0.78 | 0.45 - 1.34 | 0.369 |
| Renal disease | –0.198 | 0.82 | 0.20 - 3.39 | 0.785 |

*Age is ≥70 vs <70 years old; high-volume surgeons are compared with low- and medium-volume surgeons; race includes only white and black patients.
†Forward and backward variable selection yielded identical significant variables.

**Table VII.** Incidence and mortality rates for AAA and rAAA by year

| *AAA* | | *rAAA* | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Year* | *incidence** | *n* | *incidence** | *Mortality* | *Age (yr)* | *High-volume surgeons (%)* | *LOS (days)* | *Charge ($)* |
| 1990 | 1.39 | 91 | 0.19 | 59.3 ± 5.2 | 69.9 ± 0.9 | 19.8 | 13.2 ± 2.2 | 24,818 ± 2838 |
| 1991 | 1.34 | 82 | 0.17 | 53.7 ± 5.5 | 72.0 ± 0.9 | 13.4 | 12.6 ± 1.6 | 25,353 ± 2207 |
| 1992 | 1.31 | 75 | 0.15 | 49.3 ± 5.8 | 72.0 ± 1.0 | 20.0 | 10.8 ± 1.6 | 24,138 ± 2457 |
| 1993 | 1.36 | 100 | 0.20 | 43.0 ± 5.0 | 73.0 ± 0.8 | 18.0 | 12.1 ± 1.3 | 27,787 ± 2070 |
| 1994 | 1.17 | 91 | 0.18 | 37.4 ± 5.1 | 72.0 ± 0.7 | 15.4 | 10.4 ± 1.0 | 26,763 ± 1875 |
| 1995 | 1.22 | 88 | 0.17 | 43.2 ± 5.3 | 72.8 ± 1.1 | 17.0 | 11.8 ± 1.2 | 32,671 ± 2467 |
| *P* | | | 0.55† | 0.039† | 0.24‡ | 0.57† | 0.84‡ | 0.003‡ |

*Number of AAAs or rAAAs per 10,000 population.
†$\chi^2$ test.
‡Kruskal-Wallis test.

declined from 59% to 43% during the study interval ($P$ = 0.039). This reduction in mortality rate over the study period occurred although there was no significant change in the mean age of patients undergoing rAAA repair or in the percentage of operations performed by high-volume surgeons (Table VII).

## DISCUSSION

This recent statewide experience, which documented an overall rAAA operative mortality rate of 47.4%, affirms the significantly lethal nature of this condition and provides further insight into the factors influencing the outcome of operation. The correlation between advanced age and increased operative mortality rate confirms previous work identifying age as a significant predictor of mortality rate after both elective[6,18] and rAAA[2,14,19] repair. Although it is axiomatic that physiologic age is far more relevant than chronologic age in influencing the outcome of surgical interventions, the trend toward progressively higher medical complexity scores with advancing age in the Maryland rAAA population is evidence of more significant comorbidity among our older patient cohorts (Table II). It is interesting that there was no correlation between the medical complexity score and age among the subgroup who did not survive operation. Although the nature of the HSCRC database precluded documentation of the hemodynamic status of the patient at presentation, it is likely that the profound physiologic insult imposed by aneurysm rupture overwhelmed any potential influence of associated comorbidity on outcome in many of these cases.

In view of the rapid aging of the population and the anticipated increase in the number of elderly individuals who will present with aortic aneurysms in the future, the operative mortality rate of 66.7% among patients aged 80 and older is disconcerting. Because the majority of patients presenting with an rAAA are not aware of the presence of the lesion before rupture[20] and because AAA incidence increases with advanced age,[21] it is clear that the greatest benefit of AAA screening programs and referral for elective surgery should be realized among the very elderly. This observation notwithstanding, the current study supports an aggressive surgical approach toward the elderly patient who presents with an rAAA.[22] Although the mortality rate is higher than that in younger patients, survival occurs frequently. Furthermore, recent studies have demonstrated that elderly survivors of rAAA repair are just as likely to resume their premorbid quality of life as are younger rAAA survivors or elderly patients who undergo elective aneurysm surgery.[23] Although the charges accrued by operative survivors increase significantly with advancing age, those incurred by nonsurvivors are not influenced by age (Table II).

A number of other demographic variables and arteriosclerotic risk factors were examined in this study for their possible influence on outcome. Only 21% of the patients presenting with rAAA were women, which are consistent with previous studies.[24] The proportion of women with aortic aneurysms identified in autopsy and ultrasound studies has been somewhat higher, suggesting a possible selection bias in this and other surgical series.[24] We observed a somewhat higher mortality rate among female patients, although the difference was not statistically significant. This trend may reflect the significantly older age of female patients undergoing operation or other factors. A statewide analysis of intact AAA and rAAA repair in Michigan also noted increased operative mortality rates among women,[15] although the results of other studies have not confirmed this influence of gender on the outcome of elective[18,24] and rAAA[19,24] repair.

Although it was not surprising that multivariate analysis demonstrated an association between age and operative mortality rate, the observation that hypertension and pulmonary disease were significantly correlated with improved survival appears to be contrary to conventional wisdom (Table VI). In an analysis of 10,014 elective and rAAA repairs over an 11-year period in Michigan, Katz et al.[15] also reported a significantly lower operative mortality rate among patients with hypertension and no increased mortality rate among patients with COPD. There are a number of potential explanations for these observations. Because the current study and the report by Katz et al. retrospectively reviewed insurance coding data, it may be argued that patients identified as hypertensive or having COPD were being actively treated for these conditions, thus reducing their operative risk as opposed to other patients in whom the conditions may have existed but had not been identified and treated. Second, it is possible that patients with relatively mild manifestations of these conditions were being captured by more aggressive coding strategies in many hospitals, a phenomenon described as “DRG creep” by others.[15] Finally, one might also speculate that many rAAA patients with the most severe comorbidities died before reaching the hospital or the operating room, thus introducing a selection or underreporting bias into any assessment of the influence of those comorbid conditions on outcome.

Previous work has demonstrated an inverse relationship between rAAA operative volume and surgical outcome with respect to both operating surgeon[13,14] and hospital caseload.[14] The Maryland experience demonstrated that our high-volume rAAA surgeons are achieving optimal outcomes, including reduced operative mortality rates and lower hospital charges. This observation appears to most likely reflect surgical expertise rather than other confounding variables because the mean ages and medical complexity scores were similar among patients undergoing operation by the low-, medium, and high-volume surgeons, respectively. On the other hand, we could not relate surgical or financial outcome to the hospital rAAA or unruptured AAA operative volume (Table IV). Although high hospital volume often correlates with, and thus may be a reasonable surrogate marker for, high individual operative volume for a number of procedures, the current observation implies that this assumption might not always be valid. It has previously been suggested that optimal surgical outcome may be achieved by concentrating complex cases in high-volume institutions (i.e., by regionalizing care).[11] Although in many cases the physiologic instability of the patient with a presumed rAAA may preclude this, our data offer compelling support for the goal of directing patients to facilities with experienced aneurysm surgeons, whenever possible.

Perhaps the most remarkable observation in the current study was the significant reduction in the statewide operative mortality rate over the past 6 years. We were not able to relate this improvement to a decrease in the age of patients undergoing operation or the percentage of procedures performed by our high-volume surgeons during this interval. Several other community-based investigations have failed to demonstrate a similar improvement in outcome among patients undergoing rAAA repair,[13-15] although the majority of these operations were performed during the previous decade. It therefore is not unreasonable to speculate that the reduced operative mortality rate among patients undergoing rAAA repair most recently is a reflection of improvements in intraoperative anesthetic management, postoperative intensive care, and other factors that undoubtedly have contributed to the marked reduction in elective AAA operative mortality rate over the past two decades, although confirmation of this cumulative experience effect will require further study.

Finally, despite a greater awareness of aortic aneurysms among the medical community and the recognized mortality and morbidity rates associated with rupture, we noted no change in the incidence of rAAA during this interval in Maryland. In fact, several other population-based studies have strongly suggested an increase in the incidence of this condition in recent years.[25-27] In addition to the substantial mortality rate extracted by this condition, it represents an enormous financial burden on the health care system. The mean hospital charge for all cases in this analysis was $27,015 ± $957; it increased 33% over the 6-year interval and exceeded $32,000 per patient in 1995. Previous studies have indicated that hospital charges associated with rAAA repair exceed those of elective operation by 30% to 170%.[20,23] It was estimated that in 1979, approximately $50 million would have been saved in the United States if all rAAAs had undergone elective repair.[20] It has been understood for years that the key to reducing the mortality rate and economic burden of aortic aneurysm disease is early diagnosis and elective repair. The Maryland experience suggests that referral of patients who require rAAA repair to experienced aneurysm surgeons may improve outcome in this patient cohort traditionally associated with high operative mortality rates and cost.

## REFERENCES

1. Bodily KC, Buttorff JD. Ruptured abdominal aortic aneurysm: the Tacoma experience. Am J Surg 1985;149:580-2.
2. Donaldson MC, Rosenberg JM, Bucknam CA. Factors affecting survival after ruptured abdominal aortic aneurysm. J Vasc Surg 1985;2:564-70.
3. Richardson JD, Main KA. Repair of abdominal aortic aneurysms: a statewide experience. Arch Surg 1991;126:614-6.
4. Previti FW, Onopchenko A, Glick B. The ruptured abdominal aortic aneurysm in a community hospital: a 5-year study. Am Surg 1992;58:499-501.
5. Seiwert AJ, Elmore JR, Youkey JR, Franklin DP. Ruptured abdominal aortic aneurysm repair: the financial analysis. Am J Surg 1995;170:91-6.
6. Diehl JT, Cali RF, Hertzer NR, Beven EG. Complications of abdominal aortic reconstruction: an analysis of perioperative risk factors in 557 patients. Ann Surg 1983;197:49-56.
7. Johnston KW, Scobie TK. Multicenter prospective study of nonruptured abdominal aortic aneurysms. I. Population and operative management. J Vasc Surg 1988;7:69-81.
8. Bradbury AW, Bachoo P, Milne AA, Duncan JL. Platelet count and the outcome of operation for ruptured abdominal aortic aneurysm. J Vasc Surg 1995;21:484-491.
9. Shackleton CR, Schechter MT, Bianco R, Hildebrand HD. Preoperative predictors of mortality risk in ruptured abdominal aortic aneurysm. J Vasc Surg 1987;6:583-9.
10. Hiatt JCG, Barker WF, Machleder HI, Baker JD, Busuttil RW, Moore WS. Determinants of failure in the treatment of ruptured abdominal aortic aneurysm. Arch Surg 1984; 119:1264-8.
11. Luft HS, Bunker JP, Enthoven AC. Should operations be regionalized? The empirical relation between surgical volume and mortality. N Engl J Med 1979;301:1364-9.
12. Showstack JA, Rosenfeld KE, Garnick DW, Luft HS, Schaffarzick RW, Fowles J. Association of volume with outcome of coronary artery bypass graft surgery: scheduled vs nonscheduled operation. JAMA 1987;257:785-9.
13. Hannan EL, Kilburn H, O'Donnell JF, Bernard HR, Shields EP, Lindsey ML, et al. A longitudinal analysis of the relationship between in-hospital mortality in New York State and the volume of abdominal aortic aneurysm surgeries performed. Health Serv Res 1992;27:517-42.
14. Rutledge R, Oller DW, Meyer AA, Johnson GJ Jr. A statewide, population-based, time-series analysis of the outcome of ruptured abdominal aortic aneurysm. Ann Surg 1996;233:492-505.
15. Katz DJ, Stanley JC, Zelenock GB. Operative mortality rate for intact and ruptured abdominal aortic aneurysms in Michigan: an eleven-year statewide experience. J Vasc Surg 1994;19:804-17.
16. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chron Dis 1987; 40:373-83.
17. Romano PS, Roos LL, Jollis JG. Adapting a clinical comorbidity index for use with ICD-9-CM administrative data: differing perspectives. J Clin Epidemiol 1993;46:1075-9.

18. Starr JE, Hertzer NR, Mascha EJ, O'Hara PJ, Krajewski LP, Sullivan TM, et al. Influence of gender on cardiac risk and survival in patients with infrarenal aortic aneurysms. J Vasc Surg 1996;23:870-880.
19. Koskas F, Kieffer E. Surgery for ruptured abdominal aortic aneurysm: early and late results of a prospective study by the AURC in 1989. Ann Vasc Surg 1997;11:90-9.
20. Pasch AR, Ricotta JJ, May AG, Green RM, DeWeese JE. Abdominal aortic aneurysm: the case for elective resection. Circulation 1984;70:1-4S.
21. Ingoldby CJH, Wujanto R, Mitchell JE. Impact of vascular surgery on community mortality from ruptured aortic aneurysms. Br J Surg 1986;73:551-8.
22. Munoz E, Kassan MA, Chang JB. Surgonomics: the costs of ruptured abdominal aortic aneurysm. Angiology 1988; 39:830-7.
23. Rohrer MJ, Cutler BS, Wheeler B. Long-term survival and quality of life following ruptured abdominal aortic aneurysm. Arch Surg 1988;123:1213-7.
24. Johnston KW. Influence of sex on the results of abdominal aortic aneurysm repair. J Vasc Surg 1994;20:914-26.
25. Melton LJ III, Bickerstaff LK, Hollier LH, van Peeren HJ, Lie JT, Pairolero PC, et al. Changing incidence of abdominal aortic aneurysms: a population-based study. Am J Epidemiol 1984;120:379-86.
26. Fielding JWL, Black J, Ashton F, et al. Ruptured aortic aneurysms: postoperative complications and their etiology. Br J Surg 1984;71:487-91.
27. Drott C, Arfvidsson B, Ortenwall P, Lundholm K. Age-standardized incidence of ruptured aortic aneurysm in a defined Swedish population between 1952 and 1988: mortality rate and operative results. Br J Surg 1992;79:175-9.

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## DISCUSSION

Dr Jay G. Robison (Mount Pleasant, SC). I appreciate the opportunity to review this manuscript, and I congratulate the authors on their thought-provoking presentation. One of the strengths of this paper is the large number—527 ruptured aneurysms—reviewed over a recent 5-year period. This gives a "snapshot" of contemporary expectations for outcome after ruptured abdominal aortic aneurysm, specifically the Maryland experience. The authors attempt to tease out the factors influencing mortality rates with a careful review of a statewide database for demographic variables and for volume and experience indicators. Not surprisingly, the authors found that overall mortality rates remain high and that survivors cost more to take care of than nonsurvivors, likely because the latter have an early exit with a mean length of stay of about one third that of survivors. What is interesting and somewhat paradoxical is that lower mortality rates were seen with the comorbitities of hypertension and chronic obstructive pulmonary disease. Two thirds of patients over the age of 80 years died. Although surgeons with the greatest experience with ruptured abdominal aortic aneurysms had significantly lower mortality rates, it is difficult to ascribe the 16% statewide decline in mortality rates over the study interval to an increase in high-volume surgeon case load.

Here seems to be the crux of the issue. Because the two potentially modifiable risk factors that the authors examined (ie, operating surgeon and hospital wide experience) do not appear to account for the statewide decrease in mortality rates, what does? The authors allude to possible explanations in their manuscript as varied as improvements in anesthesia, postoperative intensive care, and improved technical expertise. But because of the limitations of the database available to them for analysis, the real reasons remain elusive.

My first question regards other modifiable variables that the authors must have considered that might not only have had a profound influence on statewide outcomes, but could conceivably skew apparent outcomes in favor of high-volume surgeons. How about stratifying outcome according to delay in transport, delay in diagnosis, time to operation, and degree of hemodynamic stability? Secondly, because only patients who were operated were involved in this data analysis, could this lead to a selection bias for patients who were considered for surgery? After all, one of my mentors told me that the key to successful vascular surgery is patient selection. Perhaps the high-volume surgeons have a sense of just who not to operate on. Furthermore, we know that not all ruptured aneurysms are the same. Is it important to distinguish a contained rupture from one with intraperitoneal leak? Another observation has to do with the demographics data. Of the 527 patients, only 10 had a smoking history and only 16% had a history of cardiac disease. This is contrary to our own experience and to that of others. If correct, these low risk factors may in part account for the decreasing mortality rates in Maryland. If not accurate, it does raise questions about the rest of the database. Lastly, I wonder if the authors could correlate patient outcomes with the training of surgeons involved in regards to vascular fellowship training. Were there more vascular surgeons in Maryland in 1995 than in 1990? There sure are in South Carolina. And I wonder if the authors might speculate as to whether the age of the surgeon might not be at least as important as the age of the patient.

Dr Alan Dardik. Thank you very much for your thoughtful discussion and comments. Regarding your first and third questions, there are many variables of interest that we cannot examine because they are not in the database. For example, there may have been a delay in transport or a delay in diagnosis in some of these patients. Unfortunately, with the nature of the database, we cannot determine that these are or are not present. Similarly, we simply cannot determine contained versus free rupture because this is not coded in the database. There are codes for elective versus urgent versus emergent repairs, but I do not think that gets to your question.

The second question you had was whether there was a selection bias by not operating. Again, with the nature of the database, we cannot figure that out at all. The codes that we used imply that we are looking at ruptured aneurysm repairs and we are not looking at all presentations of ruptured aneurysms. We know that a large percentage of these patients die before they reach the emergency room. In this report, we just select out all repairs for ruptured aneurysms because with this database we cannot examine patients who did not come to the hospital and thus did not have a repair.

The crux of this issue really is in your fourth question. Why are there decreased numbers of smoking and cardiac histories in these patients? The bottom line is that this is a reimbursement-driven database. Is this data selected to help us care for our patients? It is not. This is not an aneurysm database where somebody carefully recorded all the factors and tried to determine the true biologic response after an event. What happens is these databases are formed by coders at the hospitals and then the state and the insurance companies use them to determine all sorts of things, including capitation and payments. We looked at this database to see the data that they are using. In fact, we did determine that a lot of the risk factors, such as smoking and cardiac disease, are significantly underrepresented in the data and that one cannot believe these data. We believe that there is a tremendous statistical bias in the data for factors like this that are not well coded. We looked carefully among the literature to determine which ICD9 codes could be used to determine preexisting disease as opposed to complications of disease in terms of selecting patients and figuring out risk factors. And this is really one of the more difficult aspects of the database. We find it very interesting nonetheless that we actually can learn things from the data (eg, high-volume surgeons have better results).

And bringing us to your last question, can we determine the age or the training of the surgeon? The problem, of course, is that it is an anonymous database. For example, I know that surgeon number 304 had good data. On the other hand, I do not know who he or she is or what his or her age and training were.